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Highway 7N Pavement Response and Vehicle Damage Experiment:

Construction, Instrumentation & Monitoring

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Highway 7N Pavement Response and Vehicle Damage Experiment: Construction, Instrumentation & Monitoring

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Abstract:	Four instrumented pavement sections were constructed in 1985 on Highway 7N near Metropolitan Toronto to enable the Ministry of Transportation to investigate and quantify pavement damage caused by trucks, now and in the future. This report describes: • the construction and the design of the test sites; • properties of construction materials used, and properties of the constructed pavement sections; • instrumentation installed to evaluate pavement response to vehicle loads in terms of strains at the bottom of the asphalt concrete layers, the total pavement deflections, and pressures in the granular layers; and, • procedures established to measure, store, and retrieve long-term pavement performance data. The experimental facility has been successfully constructed and instrumented and is now being used to pursue the study objectives.

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1/ Introduction

Highway pavements are subjected to a great variety of vehicle loads which, together with environmental factors, are the major cause of pavement damage. The quantification of pavement damage caused by vehicle loads is needed for pavement design purposes, for improving knowledge of pavement response to different axle loads, axle configurations, and tire types and tire pressures, and to assist in vehicle weight regulatory studies.

The quantification of pavement damage caused by different vehicle loads is not an easy task because of the interaction between load and environmental contributions, and because of the on-going changes in the truck technology. In particular, the last two decades witnessed many changes in the character of pavement loads, such as greatly increased truck volumes, a significant increase in axle loads, development and introduction of new truck suspension systems and tires, and increased tire pressures. The Highway 7N experiment was built to enable the Ontario Ministry of Transportation to evaluate objectively pavement damage caused by the vehicle loads, now and in the future. It is the second major pavement experiment built by the Ministry; the first being the Brampton Test Road built in the mid-1960s to evaluate the strength equivalency of different base materials [1].

The specific objectives of the Hwy 7N experiment are:

a) to develop relationships between the pavement structure and the damage caused by vehicle loads in terms of load equivalency factors;

b) to quantify the relative influence of vehicle loads, such as axle loads, axle spacing and configuration, tire pressure and type, and tire arrangement (single versus dual wheels), on pavement damage;

c) to provide data for rational evaluation of benefits which can be derived from weight enforcement programs; and

d) to provide a test facility for direct evaluation of the damaging effects of typical highway vehicles.

This report describes the construction, instrumentation, and monitoring of the Highway 7N experiment, encompassing the following topics:

* design of the experiment;
* properties of construction materials used, and properties of the constructed pavement sections;
* instrumentation used to detect pavement response to vehicle loads and to measure other relevant data such as pavement temperature and moisture, and traffic loads; and
* procedures established to measure, store, and retrieve long-term pavement performance data.

It is planned to issue subsequent reports which will describe the results obtained from the experiment and which will address the specific research objectives of the experiment outlined previously.

2/ Experimental Design

The experimental section is part of a new alignment of Highway 7N, a 6-lane divided highway situated between Dufferin Street and Bathurst Street, about two km north from the Metropolitan Toronto boundary (Figure 1). The new alignment is about 4 km long and was constructed during 1985.

The experimental section consists of four pavement sites instrumented to measure pavement response to vehicle loads (Sites A, B, C and D), one additional experimental site (Site O), and a weigh-in-motion site situated between Sites B and C. The experimental sites are 150 m long and are separated by transition sections which are at least 20 m long.

The section is located in a gently rolling countryside of a glacial till plain. The predominant soil type is a silty clay of a medium plasticity derived from shales and limestones. The Sites A, B, C, and D are located on a 0.5% upgrade, Site O is located on about 1% downgrade (Figure 2).

The pavement is 11 m wide and has paved shoulders on both sides as illustrated by the cross-section drawings given in Figures 3 and 4. All sites have a conventional pavement structure with an asphalt concrete surfacing on top of granular layers. The drainage for Sites A, B, C, and D is provided by granular layers connected to lateral ditches; the drainage for Site O is provided by granular layers connected to subdrains. The detailed layout of all experimental sites, including a description of the pavement structure and the instrumentation used, is shown in Figures 5 and 6. Detailed construction drawings of the whole facility are given in Reference 2.

All instrumented experimental sites (Sites A to D) have the following pavement structural features in common:

a) they are located on the same subgrade (silty clay of medium plasticity),
b) they have the same type and thickness of granular base (150 mm of Granular A) and,
c) they have the same type and thickness of pavement surface course (40 mm of Dense Friction Course).

The instrumented sites differ in the following two structural features:

a) The thickness of the subbase (Granular B), which ranges from 150 mm on Site D to 400 mm on Site A.
b) The thickness of asphalt binder courses and, consequentially, the total thickness of the asphalt concrete layer. The total design thickness ranges from 80 mm on Site D to 140 mm on Site A.

The objective of the structural design for the four instrumented sites was to obtain one structurally adequate pavement site using a typical Ministry design (namely Site A), and three additional pavement sites which are progressively less and less structurally adequate (namely Sites B, C, and D). The uninstrumented pavement site (Site O) was built to evaluate the performance of an open-graded drainage layer. This site is not directly a part of the experimental design for the Pavement Response and Vehicle Damage Experiment, and the material properties of this section are not described in detail in this report.

Lane 3 (outside lane) of the four instrumented sites contains gauges for the measurement of the total pavement deflection, the strain at the bottom of the asphalt concrete layer, and the vertical pressure in the granular layers (Figures 5 and 6). The side-by-side arrangement of the four instrumented sites, with the weigh-in-motion site in the middle (Figure 1), was chosen to enable a direct comparison of the pavement responses to the vehicle loads, measured by the weigh-in-motion scale, for all four sites. Thus, for an individual vehicle or an axle configuration travelling at constant speed across the four pavement sites, the measured differences in the pavement response can directly be attributed to the differences in the pavement structures of the four sites. To enable cross-comparison of pavement responses to trucks passing over the sites at different times, the sites are also instrumented to measure vehicle speed and to monitor temperature and moisture of the pavement structure.

3/ Construction and Special Provisions of the Contract

The construction of the experimental section was done during the late spring and summer of 1985 as a part of the 4 km long contract. The contractor, Dufferin Construction Co., used the same excavation, compaction, hauling, and construction procedures and equipment on the experimental section as on the rest of the contract. However, for the experimental section, closer-than-usual monitoring of construction procedures was carried out by the Regional Quality Assurance Officers, and an additional monitoring and testing were done by the Research and Development Branch staff.

Special construction provisions included the following:

a) No construction traffic, other than that required for the construction of the experimental section, was allowed on the section.
b) The subgrade soil material throughout the experimental section had to be uniform.
c) The contractor was required to allow sufficient time for the Research and Development Branch staff to undertake testing of each completed layer, and to install instrumentation.

To obtain a uniform subgrade for all test sites in the top one metre subgrade layer, surplus subgrade material from the west end (Sites A and D) was moved by scrapers to fill at the east end of the section (Sites B and O, Figure 2).

Two problems of note were encountered during the construction. Firstly, Granular B material, a clean sand, used for the construction of the subbase layer could not withstand heavy truck loads. Before trucks could travel on it, Granular B material had to be end-dumped, pushed ahead by a dozer to grade, and capped with a thin layer of Granular A material (i.e., base layer material).

Secondly, in December of 1985, some areas of the surface course (Dense Friction Course -- DFC) started to exhibit severe ravelling. After further evaluation in the spring of 1986, it was noted that the areas with severe ravelling had further increased and needed repairs. This was done in June of 1986 by milling off the DFC course and replacing it with a new one. The extent of the repaired areas is shown in Figure 7.

4/ Material Properties

The properties of all paving materials used for the construction of the experimental section have been determined by extensive testing. The results of these tests were evaluated, summarized and archived. Also, a sufficient amount of paving materials (including the subgrade material), obtained by random sampling in the field, has been placed in long-term storage to enable additional extensive testing in the future.

This section of the report summarizes only the results of the most basic field and laboratory tests conducted on the paving materials. The results of more specialized tests (such as petrographic analysis of granular materials, detailed properties of asphalt cement, and various "California Bearing Ratio – density – compaction effort – moisture" relationships) are not given herein. Also not given (but available) are the results of tests conducted on materials not directly influencing the experiment, such as asphalt concrete used for paved shoulders.

The properties of materials common to all experimental sites (e.g., California Bearing Ratio of the subgrade and the gradation of Granular B material), determined by testing of several samples obtained from the individual sites, were statistically analysed to ascertain if there were any statistically significant differences between the common materials used for the individual sites. No statistically significant differences or general trends were found. For this reason, the test results of the common materials obtained for the individual sites were combined and are reported as mean results.

Quality control was based on the current Ministry material and quality assurance specifications. In general, these specifications were met.

Unless otherwise stated, all material properties reported in this report were obtained using the testing procedures given in Reference 3.

4.1/ Subgrade

Based on the gradation chart given in Figure 8 and on Attenberg limits given in Table 1, the subgrade material can be classified as a silty clay of medium plasticity. Its average California Bearing Ratio (CBR, ASTM-D1883-73) was about 4, with the standard deviation of about 2 (Table 1). The subgrade was compacted by a sheepsfoot roller and a rubber-tired roller. During the compaction, the subgrade moisture content was about 10% (Table 2), while the optimum moisture content was about 12% (Table 1). The average compaction, based on 53 nuclear density determinations [4],

was about 108% of the modified (one point) Proctor test [3]. The corresponding standard deviation was 7.2% (Table 2).

4.2/ Granular Materials

The subbase material was Granular B material obtained from a wayside pit on Bloomington Sideroad, west of Hwy 404. It had the appearance of beach sand. About 80% of the material passed #16 sieve and about 38% passed #50 sieve (Figure 9). Its average CBR (ASTM-D1883-73) was about 21, with the standard deviation of 6.4 (Table 1). The average compaction of the subbase achieved in the field, based on 35 nuclear density determinations, was 107.7% of the modified (one point) Proctor test (Table 2). The average moisture content of the Granular B material during compaction was about 5% below the Proctor optimum.

The base course material was Granular A, a crushed stone material with the CBR (ASTM-D1883-73) of about 78. Its gradation curve is shown in Figure 10. The average compaction achieved in the field, based on 17 measurements, was 102.7% based on the modified Proctor test. The corresponding standard deviation was 1.3% (Table 2).

The granular materials were compacted using vibratory steel- and rubber-tired rollers.

4.3/ Bituminous Materials

The thickness of binder course ranges from 40 mm on Site D to 100 mm on Site A. It contains the same HL-8 mix on all sites. The coarse aggregate for the binder course was crushed limestone supplied by Dufferin Quarry; the fine aggregate (passing 4.75 mm sieve) was supplied by Sherman Sand and Gravel. The gradation chart of the mix is shown in Figure 11. Its Marshall test design properties and several mix characteristics determined on the material obtained from the field, such as compaction and asphalt content, are summarized in Table 3.

Site 0, in addition to the 40 mm HL-8 binder course and the surface course, also has a 60 mm course of "modified" HL-8 (Figure 4). The modification consisted of removing a substantial portion of the fine aggregate from the HL-8 gradation to create an open-graded mix. It may be noted that Sites A and O have the same total design thickness of the asphalt concrete layer (140 mm).

The surface course on all experimental sites consists of 40 mm of DFC containing blended (coarse and fine) steel slag aggregate supplied by Steetly Industries. The gradation chart of the mix is given

in Figure 12, and its laboratory and field properties are again summarized in Table 3. As discussed in Section 3, a substantial portion of the original DFC failed and had to be replaced. The reason for the failure has been attributed to a low asphalt content and low compaction in the field.

The asphalt concrete layer was constructed course-by-course with the course thickness not exceeding 60 mm. The compaction was done by vibratory steel- and rubber-tired rollers.

All bituminous materials used the same 85/100 asphalt cement supplied by the Gulf Canada Ltd. Clarkson refinery. The basic properties of the asphalt cement are summarized in Table 4.

4.4/ Layer Thicknesses

The layer thicknesses were established during the construction by taking elevation readings at 25 m intervals at the roadway centreline and at the right edge of pavement. The separate readings were taken on the top of the finished subgrade, subbase, and base. The thickness of asphalt concrete courses was verified by radar surveys and by coring. Any corrections in the layer thicknesses were done in accordance with the standard quality assurance practice. The contractor was not required to remove surplus material, but was required to achieve the minimum specified thickness.

The layer thicknesses given in Table 5 indicate that design thicknesses of granular layers were basically achieved. The average thickness of the subbase material (Granular B) was about 0.3% higher on Site A, 3% higher on Site B, 5.5% higher on Site C, and about 2% lower on Site D, than the design thickness. The average thickness of the base material (Granular A) was about 15% higher on Site A, 6% higher on Site B, 1% higher on Site C, and about 8% higher on Site D, than the design thickness. The average combined thickness of the granular materials (Granular A plus Granular B) was higher than the corresponding design thickness on all sites.

The thicknesses of asphalt concrete layers were verified by radar surveys using DART equipment [5] and by coring. The non-destructive radar thickness verification surveys were conducted quite extensively and the thicknesses obtained by the radar were compared on several selected locations with the thicknesses determined by coring. The results are summarized in Table 6, which indicates that the design thicknesses were basically achieved and that the radar produced results similar to coring. Some of the differences between radar and coring surveys reported in Table 6 can be attributed to the differences in the coverage area of the two survey techniques. The coverage area of the radar was about 400 cm^2 [5], while the thickness obtained by coring was based on a core with an area of only 16 cm^2.

5/ Instrumentation and Monitoring

This section describes the instrumentation used to measure experimental data, such as pavement response, environmental and traffic data, and procedures used to store and analyse these data. The instrumentation described herein is that used at the end of 1987. While it is expected that various individual components will be upgraded in the future (for example, pavement deflection transducers), the overall data acquisition and monitoring system should remain relatively stable. All instrumentation was installed by Research and Development Branch staff, with the exception of the weigh-in-motion (WIM) scale and vehicle classifiers which were installed by a subcontractor.

In those cases where experimental data have been already collected and are available, example results are also given. This is done in order to illustrate the quality of data obtained by the instrumentation, and the procedures used for data storage and retrieval.

5.1/ Overview of the Data Acquisition System

The Data Acquisition System (DAS) measures and stores data on pavement response to transient and static vehicle loads. The pavement response is measured in terms of deflections, strains, and vertical stresses in the pavement structure. The vehicle loads are measured in terms of axle weight (and gross vehicle weight), axle spacing, and speed. The schematic diagram of the DAS, listing all major components of the system and their arrangement is given in Figure 13. The location of the instrumentation is shown on the left side of the diagram; the function of the instrumentation is shown on the right side of the diagram. The "on-site computer installation" listed on the diagram, is housed in an air-conditioned trailer stationed next to the right-of-way fence between Sites B and C.

The data acquisition system is based on an HP-9000 microcomputer and its appropriate hardware and software peripherals. These include 65 Mbyte hard disk, and a real-time digitizer (Figure 13). The voltage signals obtained from the measurement gauges installed in the pavement structure are transmitted to the DAS by a series of cables. The cables were installed inside a group of several protective plastic conduits which have an inside diameter of about 75 mm. The conduits run alongside the outer edge of the outside pavement shoulder, about 1.2 m below the surface. For ease of installation of the wiring, the conduits are interrupted by manholes spaced about 25 m apart (the manholes are labeled "MH" in Figures 5 and 6).

Due to the large distance between the measurement gauges and the DAS (approximately 250 m for Sites A and D), the gauge signals are amplified by signal conditioners (Metraplex 300 series, see

Figure 13). The separate signal conditioners have been installed, for all instrumented sites, in the manholes closest to the gauges . They are usually removed from the manholes when the testing is interrupted for a long period of time.

The data acquisition procedure consists of the following steps:

1. As the first axle of the on-coming vehicle passes over a test site, a magnetic loop in the pavement surface (e.g., as shown in Figure 5, loop L1 on Site A) activates the DAS. The system is initialized and the monitoring procedure starts.

2. Detailed pavement response-time data (e.g., pavement deflection versus time relationship) are acquired as the axle passes over the instrumentation embedded in the pavement. The input scan rate is changeable. It can be as high as 1000 Hz and enables testing at all highway speeds. The data are recorded by the HP-9000 computer (Figure 13) which can simultaneously monitor up to 24 channels.

3. After the vehicle passes a second loop (e.g. L2 on Site A), the recording of the pavement response data is terminated and the measured data are converted from voltages to engineering units using calibration constants. The vehicle speed between the two loops is also calculated, based on the distance between the loops and the time of passage.

4. As the vehicle passes over other sites, steps 1 to 3 are repeated.

5. After the vehicle passes over the weigh-in-motion scale, located between Sites B and C, its axle spacing(s), axle weights and its speed are determined.

6. Pavement response data obtained in step 3, and the vehicle weight data obtained in step 5 are displayed on the CRT screen by the operator. If all necessary pavement response and vehicle data are captured for a given test sequence, and other conditions are met as well, the data are stored by the operator for subsequent detailed analyses in the office. Unacceptable data are deleted by the operator in the field.

The above procedure is used to monitor pavement response to the vehicles selected from the traffic flow by the system operator. With some modifications, the procedure can also be used to monitor automatically all on-line traffic.

5.2/ Measurement of Pavement Response to Vehicle Loads

The pavement response to vehicle loads is measured in terms of:

a) the total pavement deflection,

b) longitudinal and transverse strains at the bottom of the asphalt concrete layer and,

c) vertical pressures in granular materials.

Deflection transducers and strain gauges have been installed in lane 3 on Sites A, B, C, and D; the pressure gauges were installed in lane 3 on Sites A, B, and D (Figures 5 and 6).

Both the deflection transducers and strain gauges were installed in rows of three across the outer wheel path (Figure 14). Because of transverse vehicle placement, this configuration minimizes the number of test runs required to record maximum strains and deflections under a given loading, enables transverse profiles of the pavement response to be examined, and provides backup should failure occur in any transducer [6].

Deflection Transducers

The deflection transducer measures the total pavement deflection and is comprised of a linear variable differential transformer (LVDT) mounted inside a protective casing. The transducer measures the movement between a pavement surface plate and a 3 m long reference rod (Figure 15). As the pavement deflects under the load, the surface plate deflects relative to the reference rod. The movement of the surface plate is measured by the LVDT as the change in voltage.

Strain Gauges

Wire-resistance strain gauges were embedded into 100 mm x 100 mm asphalt plates, 10 mm thick. Each plate carries two strain gauges; one of them measures the longitudinal strain (in the direction of travel) and the other one the transverse strain. The plates (supplied by the Alberta Research Council) were placed in rows of three on top of the finished Granular A layer (Figure 16), and embedded in the bottom of the asphalt concrete layer during the paving operation.

An example of pavement response to transient vehicle loads obtained by the strain gauges of the Data Acquisition System is illustrated in Figure 17. The response shown is for three longitudinal strain gauges, installed 300 mm apart across the outer wheel path (Figure 14) on Site B, to a tandem axle load. The unequal response of the three strain gauges evident in Figure 17 indicates how strain at the bottom of the asphalt concrete layer changes with transverse distance from the position of the load above.

Pressure Gauges

Pressure gauges supplied by Durham Instruments were installed at the top of the subgrade on Sites A, B, and D. An additional gauge was placed on the top of subbase on Site B. The pressure gauges use piezo-resistive strain gauges bonded to a thin membrane (Figure 18). The membrane deformation is translated by the system into vertical pressures acting on the membrane.

5.3/ Weigh-In-Motion Scale and Vehicle Classifiers

Traffic loads are measured, on a site situated between Site B and Site C, by a weigh-in-motion (WIM) scale [7] installed in lane 3, and by vehicle classifiers installed in lanes 1 and 2 . The arrangement, shown in Figure 19, also includes loop detectors, 20 m long super-flat approach and leave slabs, and cabinets housing the instrumentation. Also shown in Figure 19 is a number of piezo-electric cables embedded in the pavement to measure vehicle loads. They have been installed to compare the accuracy of different WIM measuring systems and are not part of the pavement response and vehicle damage experiment.

The WIM scale measures axle loads and spacing between axles. Based on axle configuration, the WIM scale classifies highway vehicles into passenger vehicles and 13 categories of trucks, and calculates their load in terms of the number of equivalent (80 kN) single axle loads (ESALs). The highway vehicle classification system used is shown in Table 7. The average number of ESALs for each truck category, for a given location and time, can be calculated from the WIM-supplied data and can then be used to estimate the ESALs using vehicle classification counts only. This procedure is described in the following paragraph.

Vehicle classifiers installed in lanes 1 and 2 measure only axle spacing and vehicle speed, but not axle weights. However, axle spacing information is sufficient to classify the vehicles into the same categories as those used by the WIM scale. The traffic loads in the two lanes are estimated by multiplying the number of the vehicles in a given category (obtained by the classifiers) and the corresponding average number of ESALs for that category (obtained by the WIM scale in lane 3), and then summing the loads for all vehicle categories. The traffic load data for one week obtained by this method are shown in Table 8.

The axle weight data can be electronically transferred from the WIM scale computer to the main computer of the Data Acquisition System (Figure 13). For the development of pavement damage functions, historical vehicle load data of the type given in Figure 20 are also required. They have been obtained by accumulating weekly traffic load data such as those given in Table 8.

5.4/ Temperature Measurements

Sites A, B, and D were instrumented with strings of temperature gauges. Each string consists of 10 thermocouples placed at depths raging from 13 mm to 1500 mm below the pavement surface. In addition, on Site A, one thermocouple was placed at an elevation of 1000 mm above the pavement surface to measure ambient temperatures (Figure 21). Temperature readings are obtained at regular intervals (e.g., every 30 minutes) using the temperature monitoring system schematically illustrated in Figure 13.

Example results of the temperature monitoring system, obtained for the first 3 sensors located below the pavement surface on Site A, are given in Figure 22. This type of data can be used (a) to compensate for pavement temperature differences when evaluating pavement response to vehicle loads and, (b) to quantify the effects of environmental exposure required for the development of pavement damage functions. In the latter case, the quantification is usually done in terms of freezing index, frost-depth penetration, and the number of freeze-thaw cycles. For example, considering freeze-thaw cycles, temperature data given in Figure 22 indicate that the asphalt concrete layer was subjected to approximately 5 freeze-thaw cycles during the week beginning December 20, 1987. This estimate is based on the assumption that asphalt concrete freezes and thaws at about -0.8 °C and +0.8 °C, respectively, and considering the temperature at the midpoint of the asphalt concrete layer (170 m m below the pavement surface).

5.5/ Moisture Measurements

Moisture gauges are located on all four instrumented sites below the edge of pavement of lane 3. They are placed at the interface of Granular A and Granular B materials and at the interface of Granular B and the subgrade (Figures 5 and 6). The moisture measurements are done using Time-Domain Reflectometry technology [8] as a percentage of volumetric content of free, unfrozen water. The moisture gauges are not connected to the Data Acquisition System, and readings are done at each site by displaying the measured signal on a CRT or by plotting them using a plotter.

Example results of moisture measurements for Site A given in Figure 23 show the variation of moisture with the season of the year and with the location of sensors in the pavement structure. The moisture measured between Granular A and B layers is significantly lower than that measured between Granular B and subgrade layers.

5.6/ Performance Monitoring

5.6.1/ Visible Pavement Surface Distresses

The visible pavement surface distresses are periodically monitored by:

a) taking video images of the entire pavement surface using an Automatic Road Analyser (ARAN) [9];
b) conducting manual surveys according to the standardized procedures given in Ref. 10 which are used by the Ministry for pavement performance evaluation;
c) mapping all surface cracks on a grid paper to monitor their growth; and
d) measuring pavement profile (including rutting) using ARAN's dual accelerometers and acoustical sensors.

To date, approximately 2 $^1/_2$ years after construction, there are few visible distresses on the experimental sites. Of these, the predominant distresses are slight ravelling and hairline pavement edge cracking.

5.6.2/ Pavement Roughness

In addition to yearly measurements of pavement roughness by a response-type roughness measuring device (PURD), the longitudinal profiles of the test sites are measured twice a year by rod-and-level surveys. The elevations are taken at 1 m intervals in the right wheelpath of each lane. The measurement points are marked by nails which were set in the surface shortly after paving. The measurements are tied to frost-proof benchmarks and can be used to assess both seasonal and long-term deformations of the pavement surface.

Example results shown in Figure 24 indicate that while the pavement elevations have changed with time, the pavement roughness has remained relatively constant.

5.6.3/ Deflection Measurements and Measurements of Moduli of Elasticity

Pavement deflections are periodically measured using a Falling Weight Deflectometer (FWD) [11]. To date, deflection measurements were done on three occasions (fall of 1986, summer of 1987, and fall of 1987). The results were also used to establish moduli of elasticity of pavement layers. The results of deflection measurements, in terms of temperature-corrected maximum centre deflections, are summarized in Table 9.

6/ Conclusions

The Highway 7N experimental test sites have been successfully and expeditiously constructed by a private contractor and instrumented by the Research and Development Branch. The construction was done as a part of a large contract. The overall quality of construction was acceptable in spite of the need to replace sections of the surface course. The experimental facility is now used to quantify the damaging effects of vehicle loads, and to study the performance of different pavement designs.

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Table 1/ Results of Proctor and CBR Tests on Subgrade and Granular Materials

Material Type	Parameter	Characteristics				
		Proctor Density Tests			Attenberg Limits	
		Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)	CBR (%)	Liquid Limit (%)	Plastic Limit (%)
Granular A	mean	2.271	6.8	77.8	N/A	N/A
	st. dev.	0.038	0.7	10.9		
	number	5	5	5		
Granular B	mean	1.925	10.0	20.8	N/A	N/A
	st.dev.	0.053	1.1	6.4		
	number	27	27	7		
Subgrade	mean	1.925	11.9	4.2	19.97	11.41
	st. dev.	0.071	2.3	1.7	9.39	4.61
	number	11	11	8	14	14

N/A = Not Applicable

Table 2 / Results of Nuclear Gauge Density Tests on Subgrade and on Granular Materials

Material Type	Number of Tests	Dry Density (g/cm^3)		Moisture Content (%)		Compaction (%)	
		mean	s. d.	mean	s. d.	mean	s. d.
Granular A	17	2.23	0.03	2.49	0.83	102.7	1.3
Granular B	35	1.92	0.08	4.93	1.51	107.7	5.2
Subgrade	53	1.91	0.14	10.14	3.33	107.6	7.2

Table 3/ Results of Density, Marshall and Compaction Tests for Dense Friction Course (DFC) and Binder Course (HL-8)

Material Type	Parameter	CHARACTERISTICS							
		Bulk Relative Density (g/cm^3)	Maximum Relative Density (g/cm^3)	Marshall Tests				Other Tests	
				Voids (%)	Flow (%)	Stability (N)	V.M.A. (%)	Asphalt Cement (%)	Compaction (%)
DFC	DESIGN	2.880	3.001	2.0	18.5	19,900	12.2	5.50	N/A
	FIELD								
	mean	2.902	2.978	2.3	16.5	16,315	12.6	5.37	93.2
	st. dev.	0.053	0.216	1.2	2.3	4,037	2.1	0.52	1.85
	number	20	20	20	20	20	20	22	4
HL-8	DESIGN	2.331	2.548	3.8	9.9	13,450	14.8	5.50	N/A
	FIELD								
	mean	2.394	2.513	3.1	10.5	13,223	14.4	5.77	96.5
	st. dev.	0.008	0.036	0.4	1.2	3,291	1.2	0.26	0.36
	number	3	3	3	3	3	3	3	4

Table 4/ Results of Penetration Tests on 85/100 Asphalt Cement

Temp. (°C)	Time (s)	Mass (g)	Penetration[a]		
			Original (0.1 mm)	A.T.F.O.[b] (0.1 mm)	% Original
25	5	100	88	63	71.6
4	60	200	18	12	66.7
4	5	100	4	2	50.0

a) ASTM Method of Test D5
b) After Thin Film Oven (test)

Table 5/ Layer Thicknesses

Site and Station Number	MATERIAL TYPE			
	Granular B		Granular A	
	Right Edge of Pavement mm	Center Line mm	Right Edge of Pavement mm	Center Line mm
		SITE A		
Design Thickness	535	400	150	150
26+400	602	472	189	199
26+425	517	462	169	139
26+450	446	372	179	189
26+475	450	422	179	149
26+500	541	415	159	169
26+525	540	388	156	186
Mean	516	422	172	172
Stan. Dev.	55	36	12	22
		SITE B		
Design Thickness	435	300	150	150
26+575	406	298	175	165
26+600	458	298	125	145
26+625	451	308	165	175
26+650	475	328	145	145
26+675	432	348	165	145
26+700	428	308	135	165
Mean	442	315	152	157
Stan. Dev.	22	18	18	12

Table 5/ Layer Thicknesses (Continues from the previous page)

Site and Station Number	MATERIAL TYPE			
	Granular B		Granular A	
	Right Edge of Pavement mm	Center Line of mm	Right Edge of Pavement mm	Center Line of Pavement mm
		SITE C		
Design Thickness	485	350	150	150
26+775	645	378	63	85
26+800	530	354	79	275
26+825	480	384	149	165
26+850	496	334	139	175
26+875	506	350	139	175
26+900	480	350	189	185
Mean	523	358	126	177
Stan. Dev.	57	17	43	55
		Site D		
Design Thickness	285	150	150	150
26+950	379	131	152	217
26+975	307	106	130	212
27+000	335	81	73	207
27+025	286	76	140	202
27+050	292	111	140	187
27+075	290	166	130	142
Mean	315	112	128	195
Stan. Dev.	33	30	25	25

Table 6, Verification of Thicknesses of Asphalt Concrete Layers by Coring and Radar Surveys

Site	Location	Thickness[a], mm						
		Nominal Thickness			Coring[b]			Radar[c]
		DFC	HL8	Total	DFC	HL8	Total	Total
A	Beginning of Site	40	50	90	30	95	125	125
	End of Site	40	50	90	40	85	125	125
B	Beginning of Site	40	50	90	40	60	100	90
	End of Site	40	50	90	40	40	80	80
C	Beginning of Site	40	50	90	80	45	125	125
	End of Site	40	50	90	50	55	105	85
D	Beginning of Site	40	40	80	45	45	90	90
	End of Site	40	40	80	25	65	90	65

Notes: a) Right wheelpath in lane 3.

b) Based on sample cores with 45 mm diameter.

c) Equipment used is described in Reference 5.

Table 7/ Vehicle Classification System

Class	Type	Description
0	PVLC	Cars and other 2 axle vehicles not in Class 1.
1	2	Two axle vehicles with dual tires on the rear axle or the weight of axle 2 ≥ 1800 kg.
2	3	Three axle vehicles, distance between axles 2 and 3 ≤ 2.4 m (tandem).
3	UD-3	All other 3 axle vehicles not in Class 2.
4	2S2	Four axle vehicles, distance between axles 2 and 3 ≥ 2.4 m and distance between axles 3 and 4 ≤ 2.4 m.
5	UD-4	All other 4 axle vehicles not in Class 4.
6	3S2	Five axle vehicles, distance between axles 2 and 3, and axles 4 and 5 ≤ 2.4 m.
7	UD-5	All other 5 axle vehicles, not in Class 6.
8	3S3	Six axle vehicles, distance between axles 1 and 2 ≤ 4.5 m and axles 4 and 5 ≤ 2.4 m.
9	UD-6	All other 6 axle vehicles not in Class 8.
10	3S2-2	Seven axle vehicles, distance between axles 1 and 2 ≤ 3.2 m axles 2 and 3 ≤ 2.4 m (tandem), and axles 3 and 4 ≥ 5.2 m.
11	UD-7	All other 7 axle vehicles not in Class 10.
12	UD-8	All 8 axle vehicles.
13	UD-9+	All vehicles with 9 or more axles.

Table 8/ Traffic Loads Obtained by WIM Scale and Classifiers
(Week ending July 26, 1987)

Vehicle Type[a]	WIM SCALE			CLASSIFIERS			
	Lane 3			Lane 1		Lane 2	
	No. of Vehicles	ESAL	No. of ESAL per Vehicle	No. of Vehicles	ESAL	No. of Vehicles	ESAL
PV	10980			43289		39605	
2	567	202.94	0.34	1765	600.38	2957	991.21
3	378	538.15	1.42	200	282.70	946	1346.75
UD-3	45	17.43	0.39	30	11.80	72	27.96
2-S2	84	86.03	1.07	12	12.40	123	136.01
UD-4	64	98.56	1.41	28	37.07	62	82.15
3-S2	282	523.69	1.91	68	127.84	647	1253.97
UD-5	37	24.78	0.75	14	11.51	52	40.80
3-S3	47	89.53	1.89	9	15.09	123	233.09
UD-6	66	458.73	6.56	24	162.33	111	697.38
3-S2-2	19	153.98	7.92	1	7.33	31	242.77
UD-7	1	166.36	14.20	4	30.12	24	215.46
UD-8	29	184.34	5.82	5	26.31	48	266.71
UD-9	0	0.00		0	0.00	0	0.00
TOTAL	12615	2544.52		45449	1324.88	44801	5534.26

a) See Table 7

Table 9/ Summary of FWD Deflection Data; Central Sensor, Right Wheelpath

Site	Design Equiv. Gran. Thick. (mm)	Lane No.	Fall 1986		Summer 1987		Fall 1987	
			Mean (mm)	Stand. Dev. (mm)	Mean (mm)	Stand. Dev. (mm)	Mean (mm)	Stand. Dev. (mm)
A	746	3			0.40	0.02	0.32	0.03
B	530	1	0.43	0.02	0.41	0.03	0.50	0.02
		2	0.40	0.05	0.45	0.04	0.52	0.05
		3	0.49	0.05	0.47	0.04	0.51	0.04
C	563	1	0.40	0.02	0.37	0.03	0.41	0.03
		2	0.45	0.04	0.43	0.03	0.45	0.05
		3	0.44	0.06	0.45	0.04	0.44	0.07
D	410	1	0.55	0.05	0.46	0.07	0.49	0.05
		2	0.55	0.04	0.49	0.08	0.56	0.05
		3	0.59	0.06	0.56	0.07	0.60	0.07

Note: For Site A, the sample size was 5; for Sites B, C, and D, the sample size was 10 for each lane.

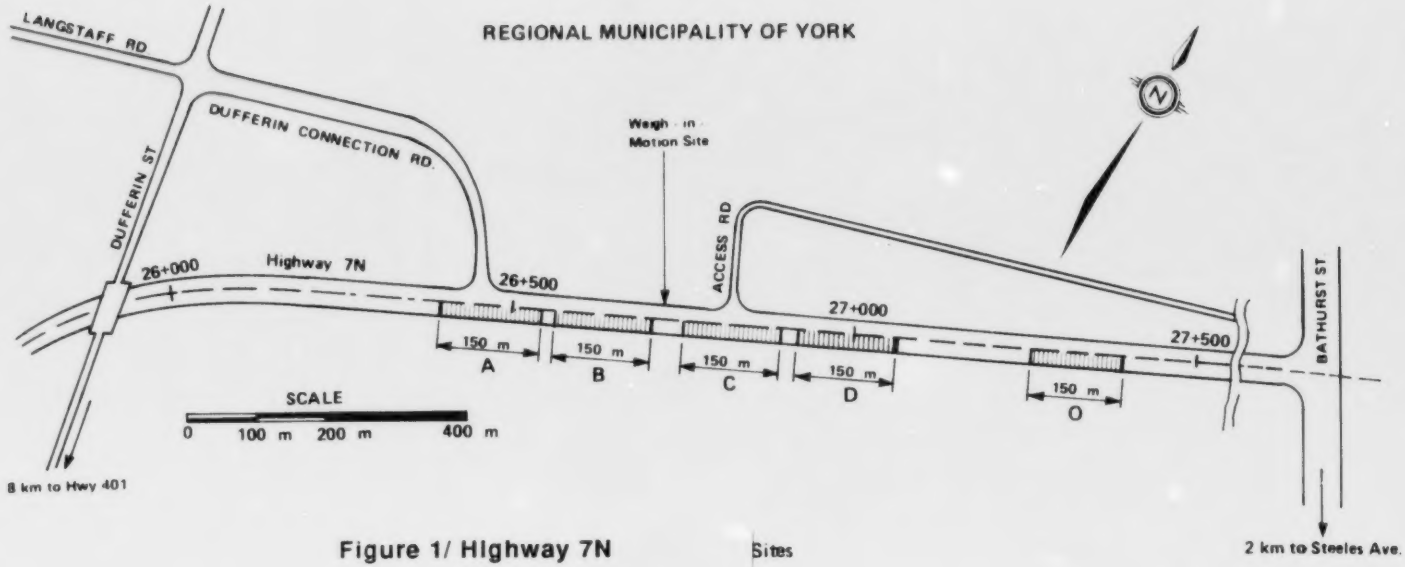
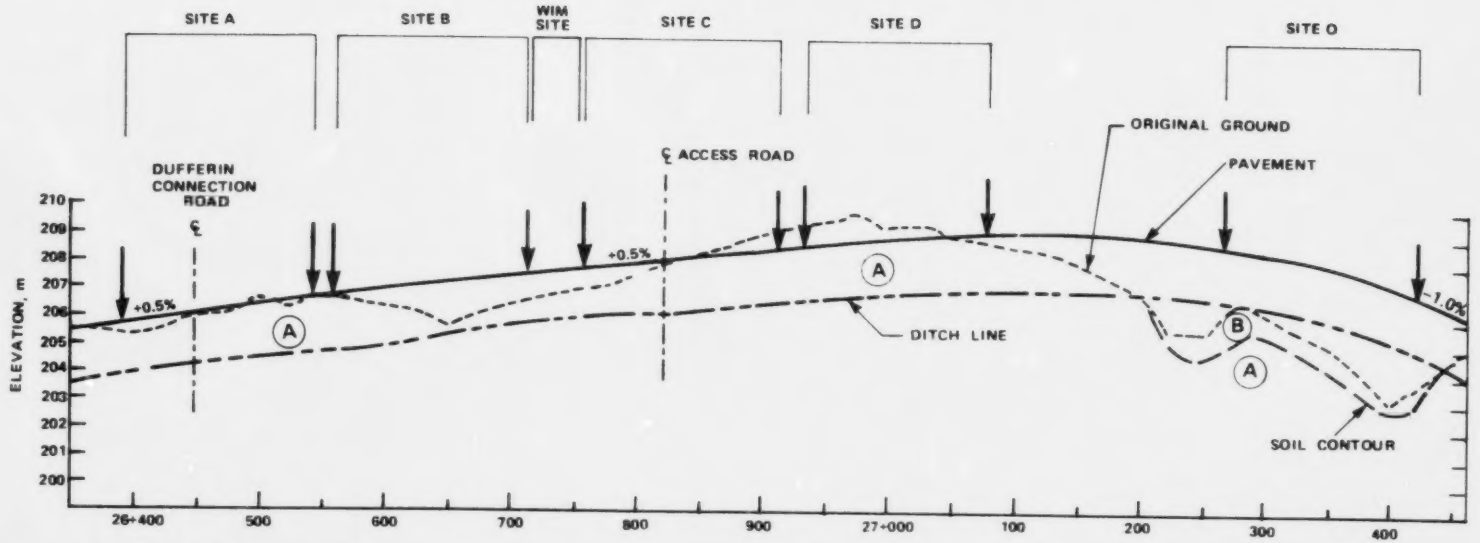


Figure 1/ Highway 7N Sites



NOTES ON SUBGRADE MATERIALS

- Topsoil consisted of dark-brown silty clay 75 to 200 mm (Removed)
- (A) Brown, silty clay of medium plasticity
- (B) Brown, silty sand, stony
- To obtain uniform subgrade for top 1 m,material from out at west end was moved by scraper to fill at east end of the test section

HORIZONTAL SCALE: 50 m 0 100 m

VERTICAL SCALE: 1 m 0 2 m

Figure 2/ Pavement and Soil Profile, Hwy 7N

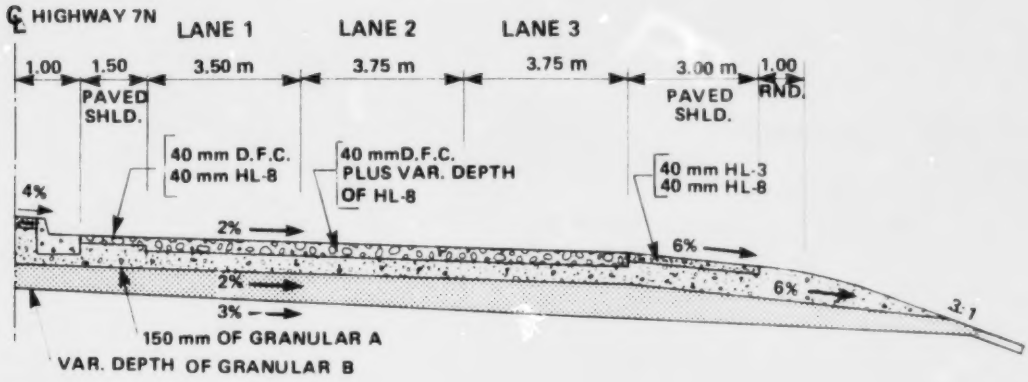


Figure 3/ Typical Cross-Section for Sites A,B,C and D

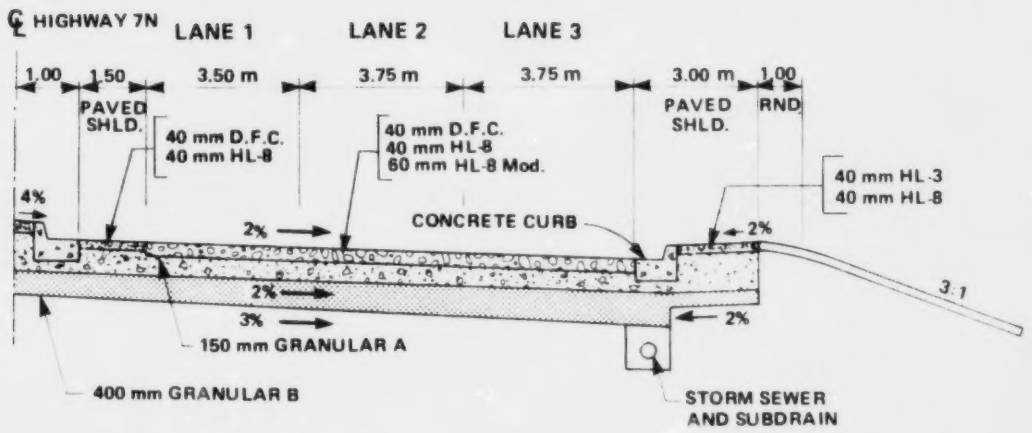
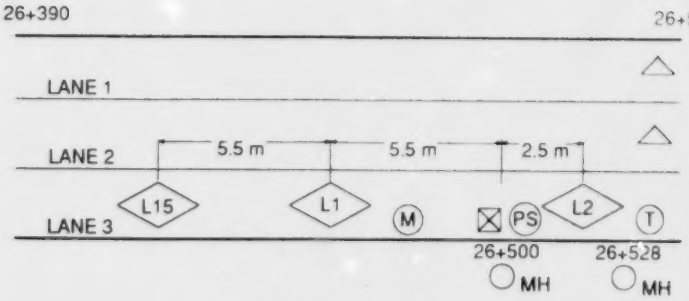


Figure 4/ Cross-Section for Site O (Sta. 27+270 to 27+420)

SITE A



DEFLECTION AND STRAIN GAUGES ⊠

Deflection	Strain	
	Longitud.	Trans.
A-1	AL-4	AT-4
A-2	AL-5	AT-5
A-3	AL-6	AT-6

DEFLECTION OR STRAIN △

LANE 1	LANE 2
A-7	A-10
A-8	A-11
A-9	A-12

MOISTURE GAUGES (M)

AM-1 top of 'B'
AM-2 top of 'S.G.'

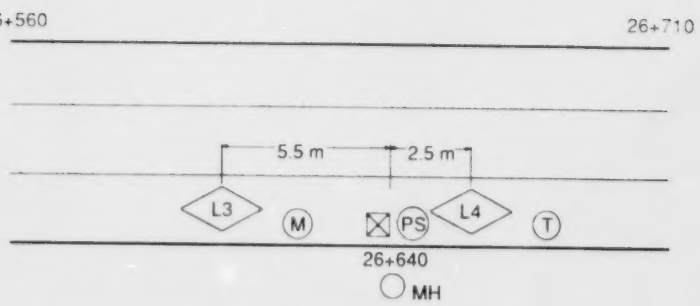
TEMPERATURE GAUGES (T)

ATMP-1 to ATMP-10

PRESSURE GAUGE (PS)

AP-1 top of 'S.G.'

SITE B



DEFLECTION AND STRAIN GAUGES ⊠

Deflection	Strain	
	Longitud.	Trans.
B-1	BL-4	BT-4
B-2	BL-5	BT-5
B-3	BL-6	BT-6

TEMPERATURE GAUGES (T)

BTMP-1 to BTMP-10

MOISTURE GAUGES (M)

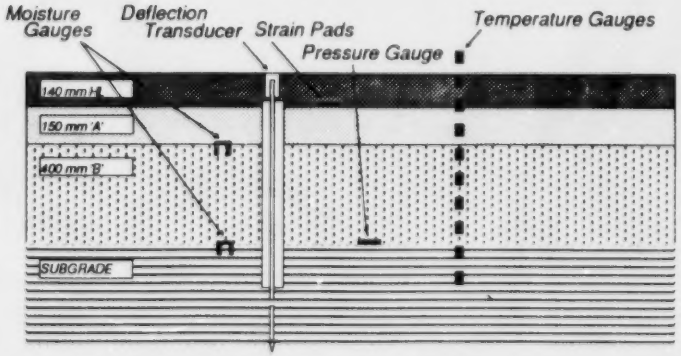
BM-1 top of 'B'
BM-2 top of 'S.G.'

LOOP DETECTORS ◇

L1 to L4, and L15

PRESSURE GAUGES (PS)

BP-1 top of 'B'
BP-2 top of 'S.G.'



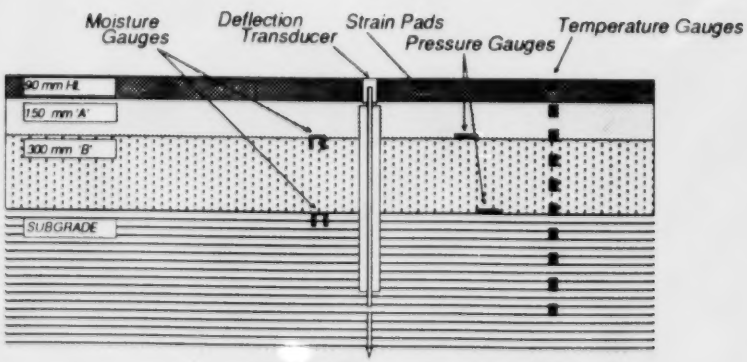
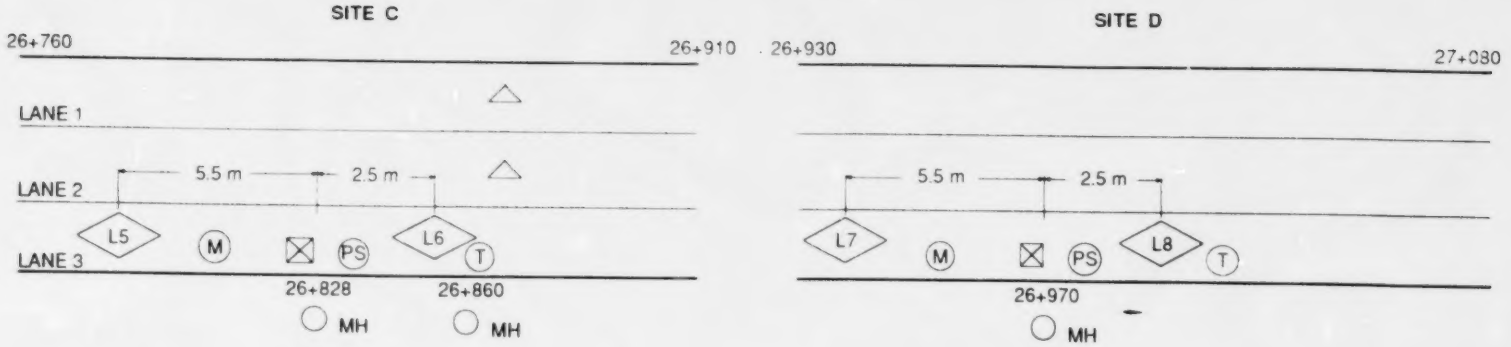


Figure 5/ Layout of Sites A and B



DEFLECTION AND STRAIN GUAGES ⊠

Deflection	Strain Longitud.	Strain Trans.
C-1	CL-4	CT-4
C-2	CL-5	CT-5
C-3	CL-6	CT-6

LOOP DETECTORS ◇
L5 to L8

DEFLECTION OR STRAIN △

LANE 1	LANE 2
C-7	C-10
C-8	C-11
C-9	C-12

MOISTURE GAUGES (M)
CM-1 top of 'B'
CM-2 top of 'S.G.'

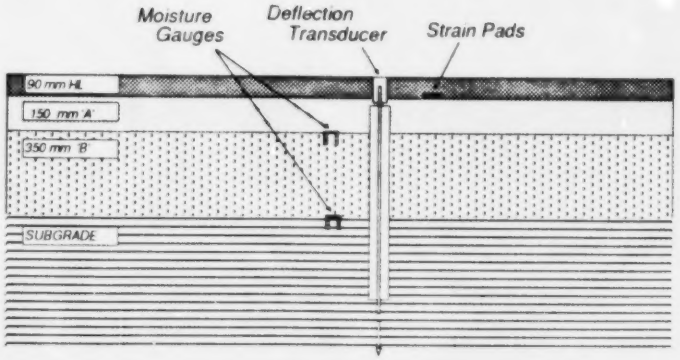
DEFLECTION AND STRAIN GAUGES ⊠

Deflection	Strain Longitud.	Strain Trans.
D-1	DL-4	DT-4
D-2	DL-5	DT-5
D-3	DL-6	DT-6

TEMPERATURE GAUGES (T)
DTMP-1 to DTMP-10

MOISTURE GAUGES (M)
DM-1 top of 'B'
DM-2 top of 'S.G.'

PRESSURE GAUGE (PS)
DP-1 top of 'SG'



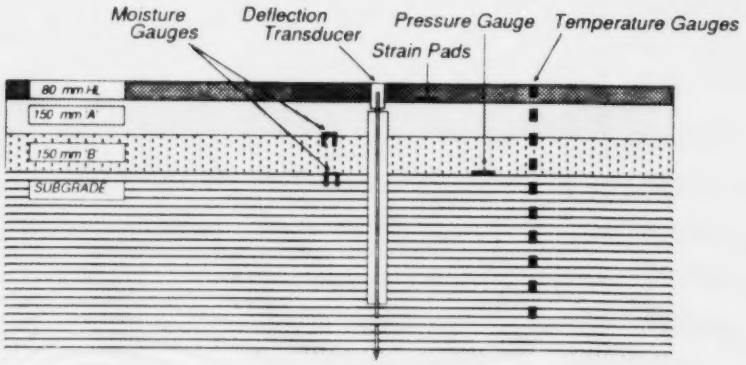


Figure 6/ Layout of Sites C and D

LEGEND

- Areas where DFC was milled off and replaced in June 1986
- DFC on Sites B and C was milled off and replaced entirely in June 1986
- No repairs were done on Site O

Figure 7/ Location of Areas Where the Surface Course (DFC) was Repaired

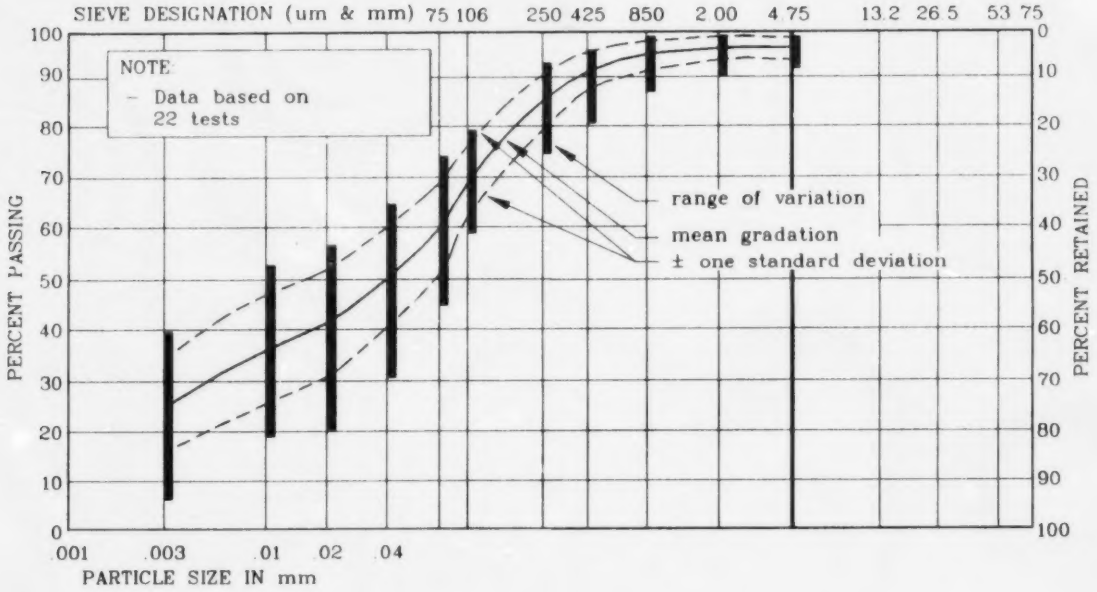

SIEVE DESIGNATION (um & mm) 75 106 250 425 850 2 00 4 75 13.2 26 5 53 75
NOTE
– Data based on 22 tests
range of variation
mean gradation
± one standard deviation
PERCENT PASSING
PERCENT RETAINED
PARTICLE SIZE IN mm
.001 .003 .01 .02 .04

Figure 8/ Gradation Chart for Subgrade Material

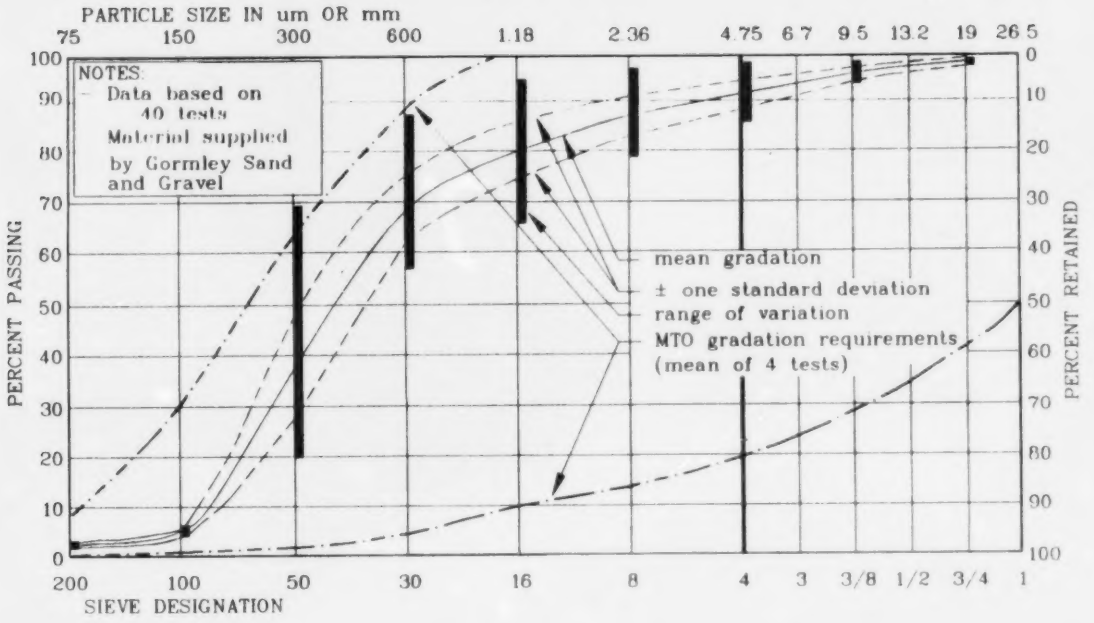

PARTICLE SIZE IN um OR mm
75 150 300 600 1.18 2.36 4.75 6.7 9.5 13.2 19 26.5
NOTES:
- Data based on 40 tests
Material supplied by Gormley Sand and Gravel
mean gradation
± one standard deviation
range of variation
MTO gradation requirements (mean of 4 tests)
PERCENT PASSING
PERCENT RETAINED
SIEVE DESIGNATION
200 100 50 30 16 8 4 3 3/8 1/2 3/4 1

Figure 9/ Gradation Chart for Subbase Material (Granular B)

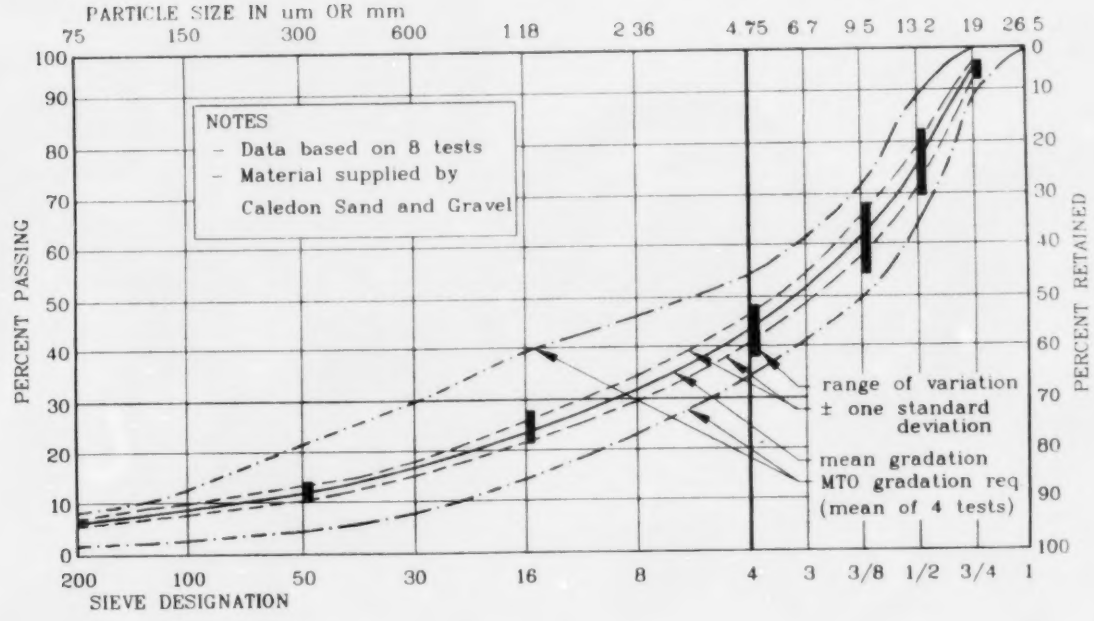

PARTICLE SIZE IN um OR mm
75 150 300 600 1.18 2.36 4.75 6.7 9.5 13.2 19 26.5
NOTES
- Data based on 8 tests
- Material supplied by Caledon Sand and Gravel
range of variation
± one standard deviation
mean gradation
MTO gradation req (mean of 4 tests)
PERCENT PASSING
PERCENT RETAINED
SIEVE DESIGNATION
200 100 50 30 16 8 4 3 3/8 1/2 3/4 1

Figure 10/ Gradation Chart for Base Material (Granular A)

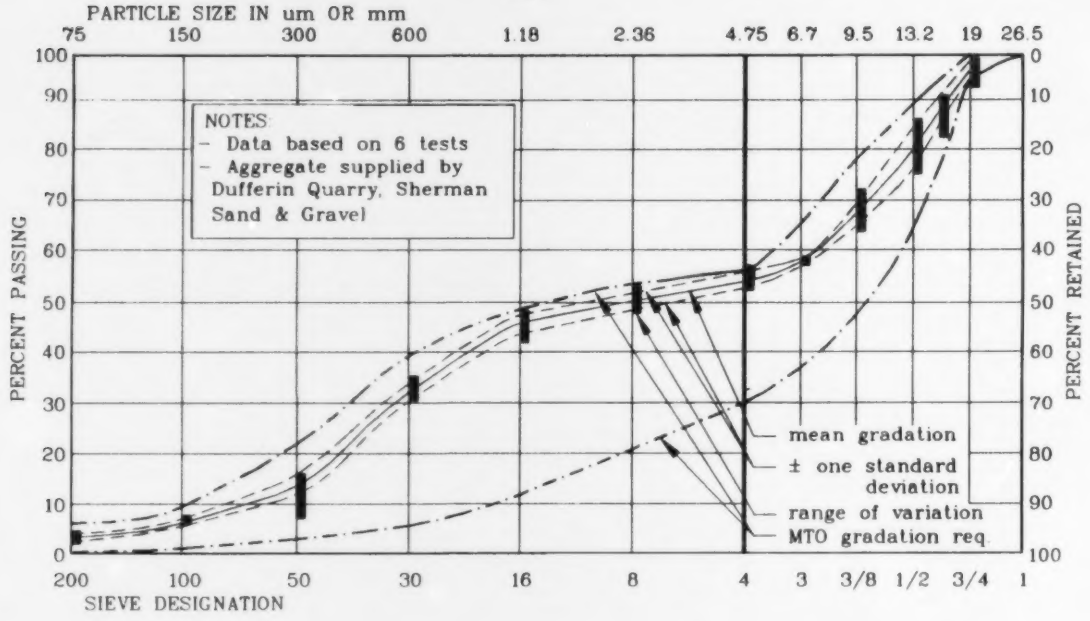

PARTICLE SIZE IN um OR mm
75 150 300 600 1.18 2.36 4.75 6.7 9.5 13.2 19 26.5
PERCENT PASSING
PERCENT RETAINED
NOTES:
- Data based on 6 tests
- Aggregate supplied by Dufferin Quarry, Sherman Sand & Gravel
mean gradation
± one standard deviation
range of variation
MTO gradation req
200 100 50 30 16 8 4 3 3/8 1/2 3/4 1
SIEVE DESIGNATION

Figure 11/ Gradation Chart for Binder Material (HL 8)

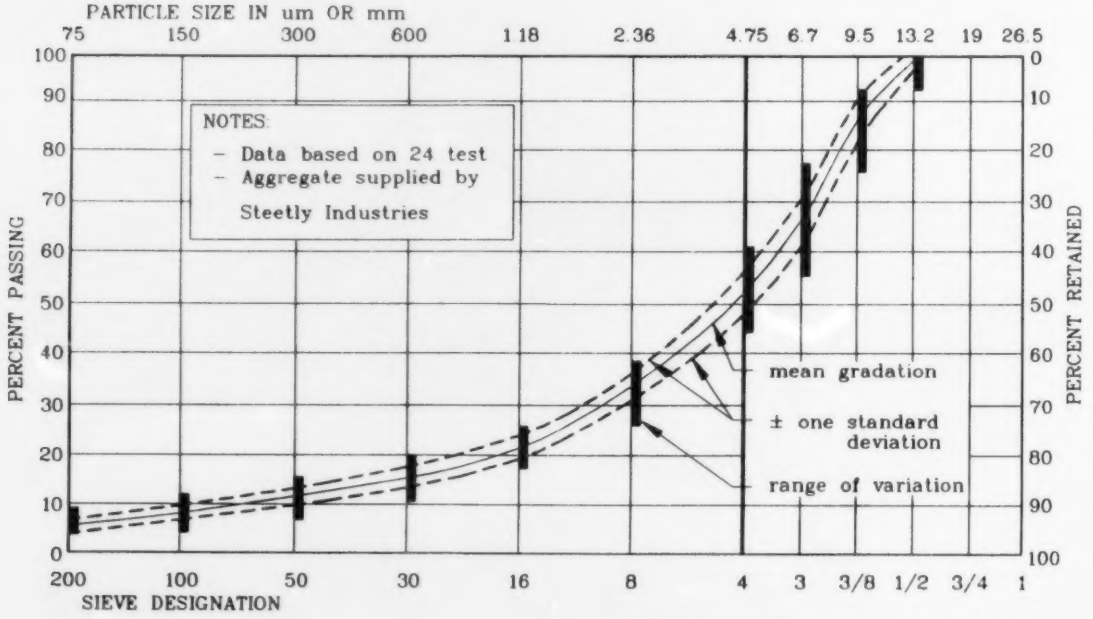

PARTICLE SIZE IN um OR mm
75 150 300 600 1.18 2.36 4.75 6.7 9.5 13.2 19 26.5
PERCENT PASSING
PERCENT RETAINED
NOTES:
- Data based on 24 test
- Aggregate supplied by Steetly Industries
mean gradation
± one standard deviation
range of variation
200 100 50 30 16 8 4 3 3/8 1/2 3/4 1
SIEVE DESIGNATION

Figure 12/ Gradation Chart for Dense Friction Course

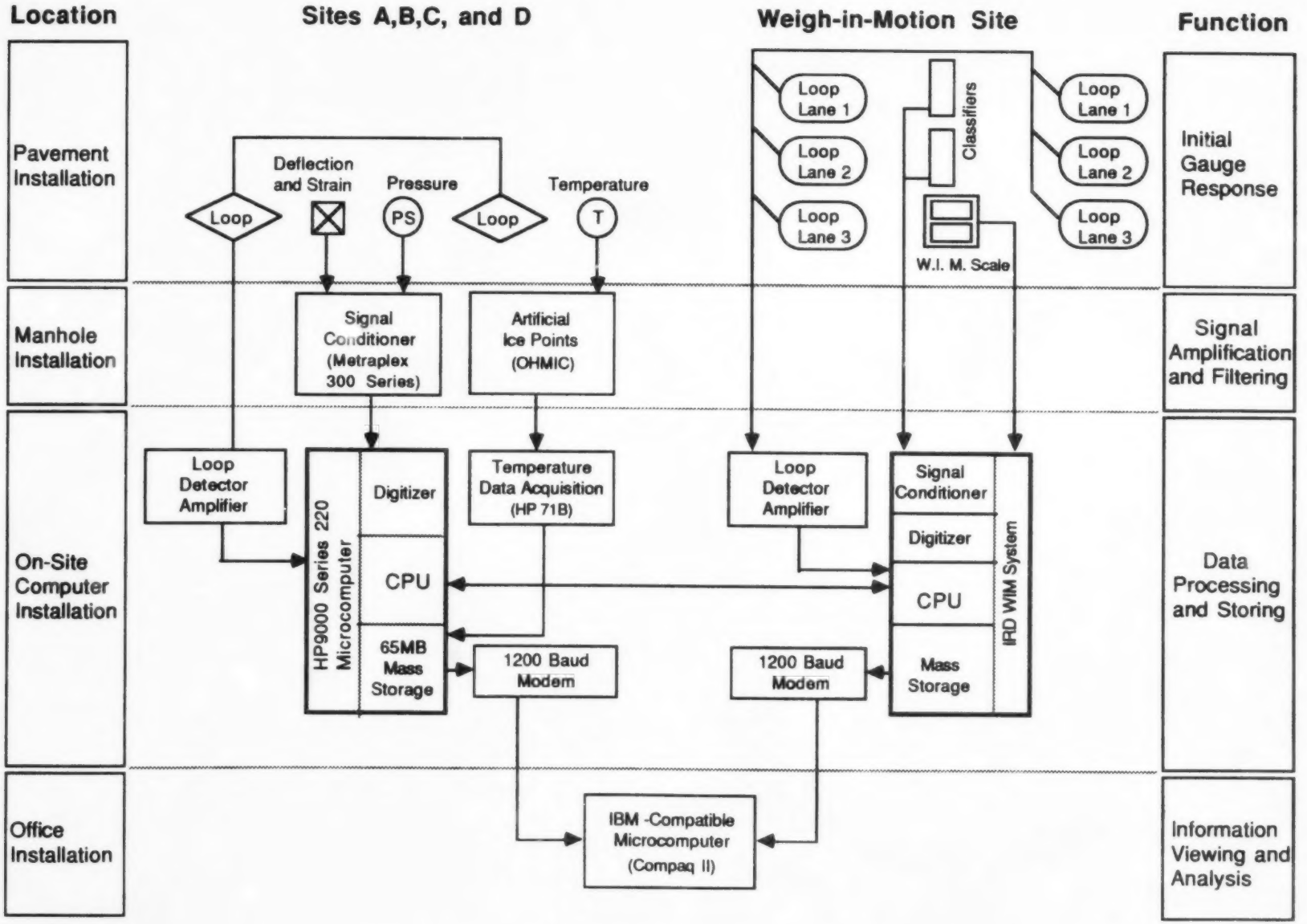


Figure 13/ Schematic Diagram of Data Acquisition System

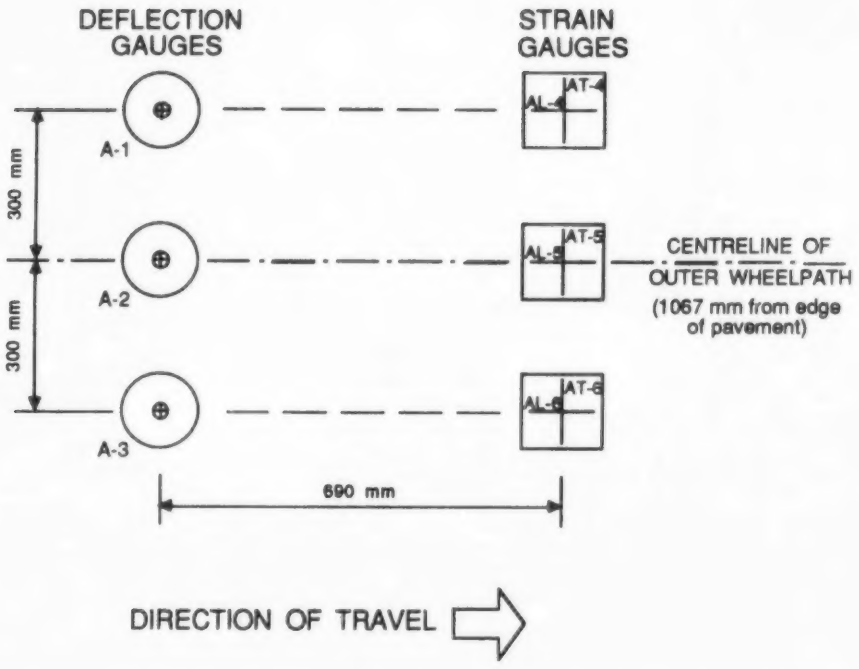
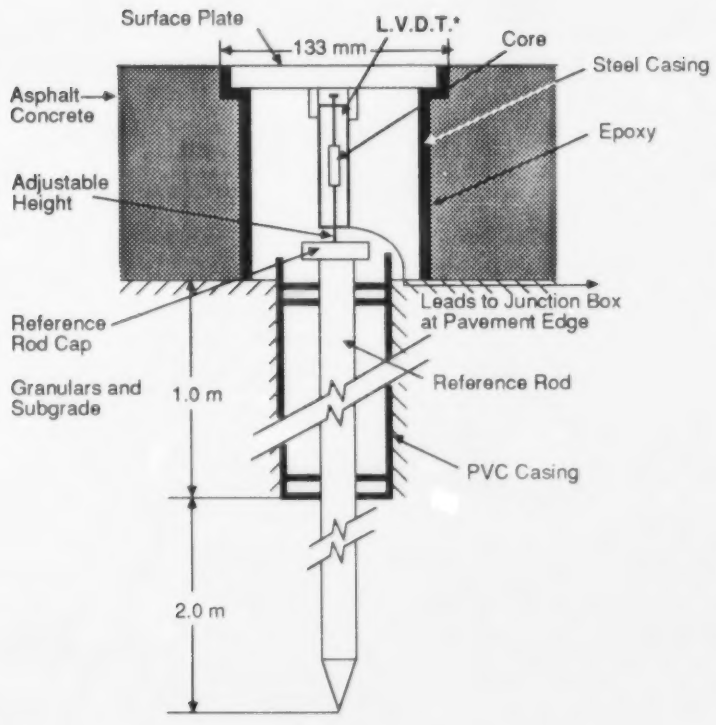


Figure 14/ Typical Transducer Layout (Site A, Station 26+525)



* Linear Variable Differential Transformer

Figure 15/ Structure of Deflection Transducers

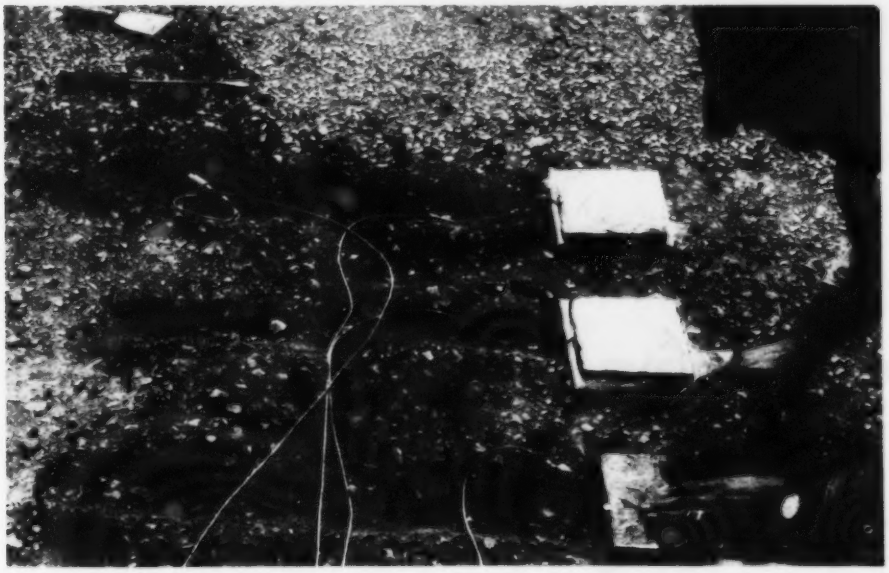


Figure 16/ Placement of Strain Gauges on Granular A

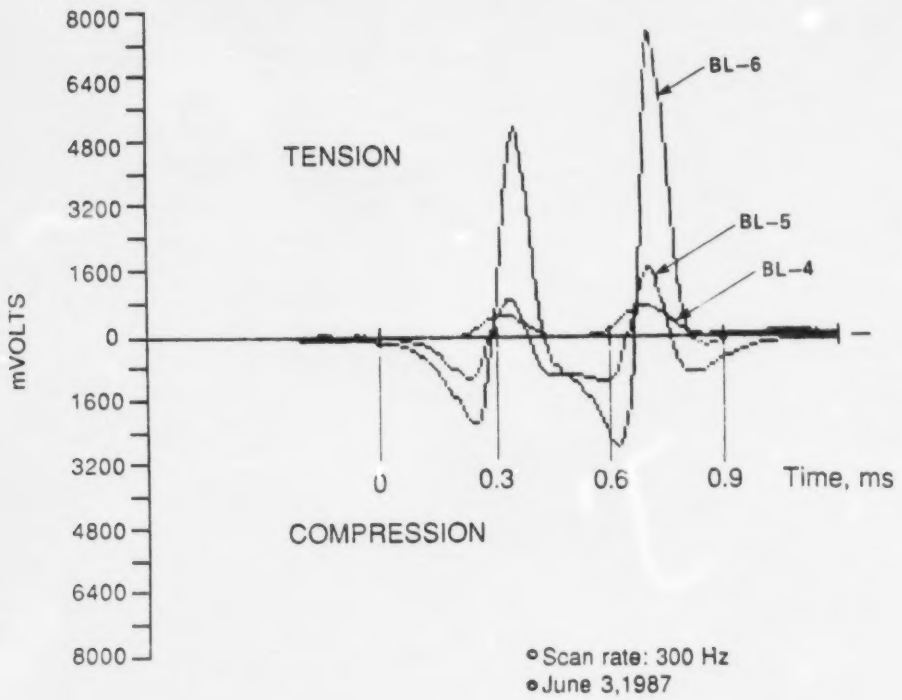


Figure 17/ Example of Longitudinal Strain Response Profile to Tandem Axle Load, Site B

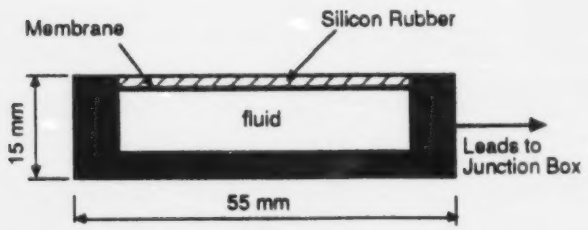
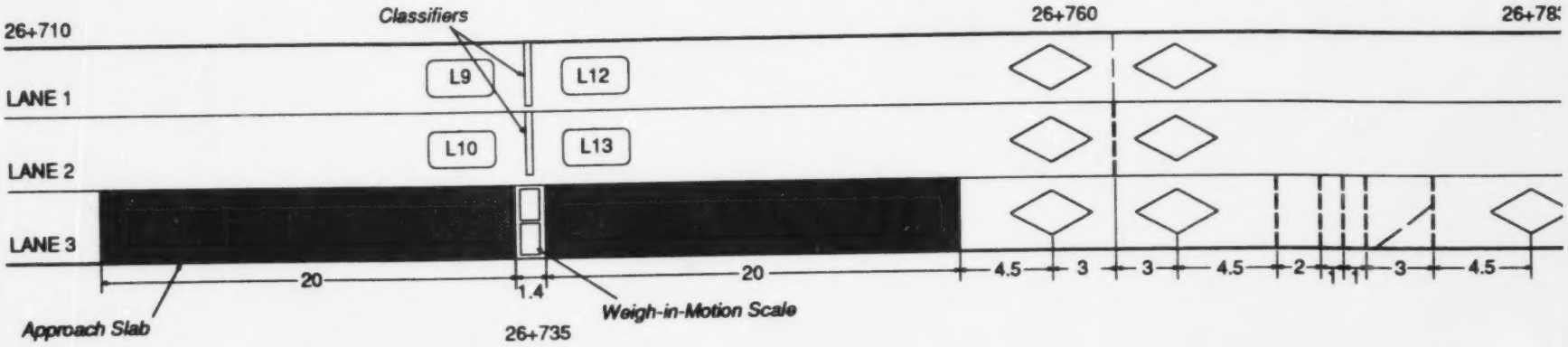


Figure 18/ Structure of Pressure Gauges



CABINET C1

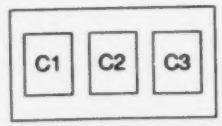
LOOP DETECTORS, AMPLIFIERS ELECTRONICS

CABINET C2

W.I.M. AND CLASSIFIER ELECTRONICS

CABINET C3

PIEZOELECTRIC CABLE ELECTRONICS



INSTRUMENTATION CABINETS

PIEZOELECTRIC CABLES

LOOP DETECTORS

* All measurements are in metres

Figure 19/ Layout of Weigh-in-Motion Site and Piezoelectric Cables

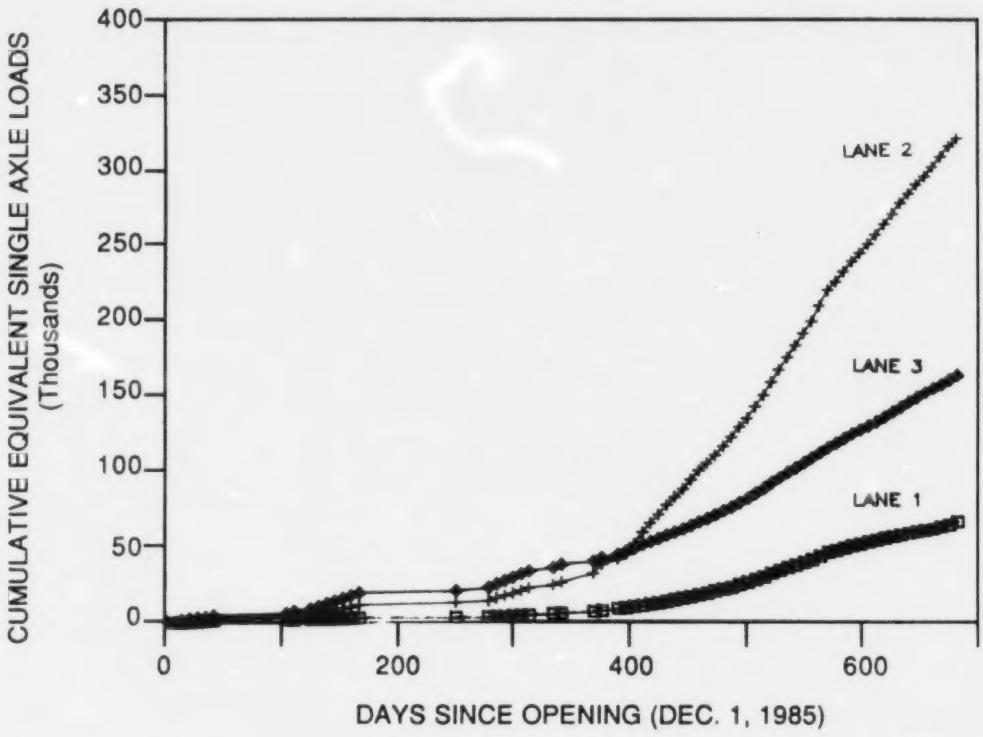
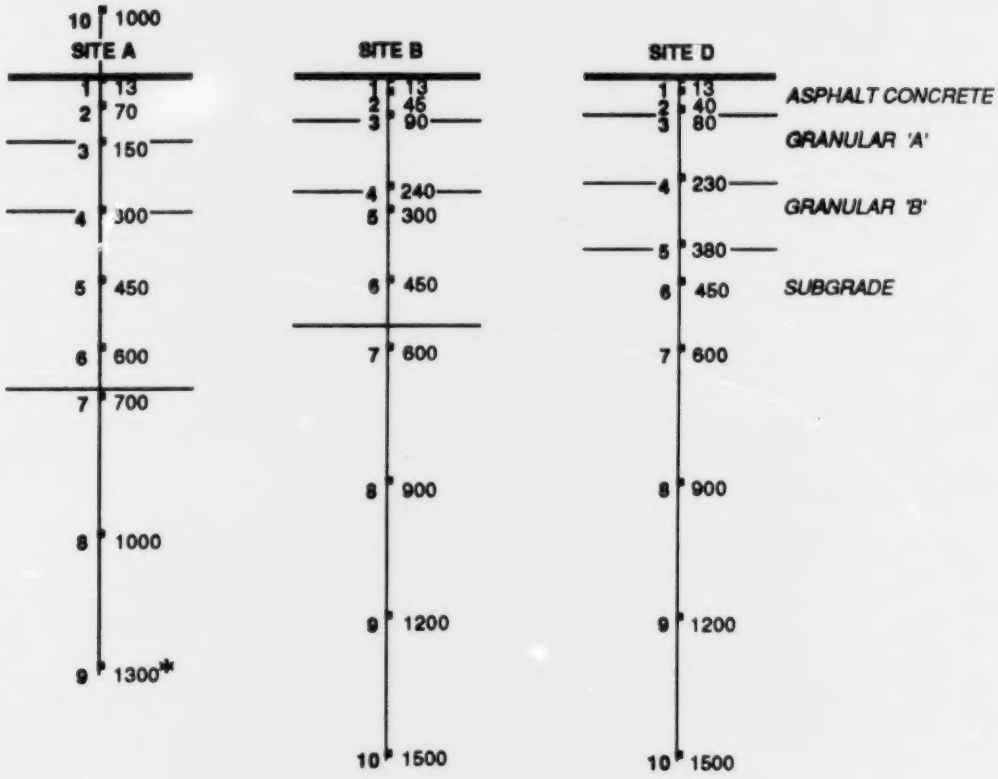


Figure 20/ Cumulative Equivalent Single Axle Loads for the First 700 Days



* Depths of sensors are in millimetres

Figure 21/ Layout of Temperature Gauges

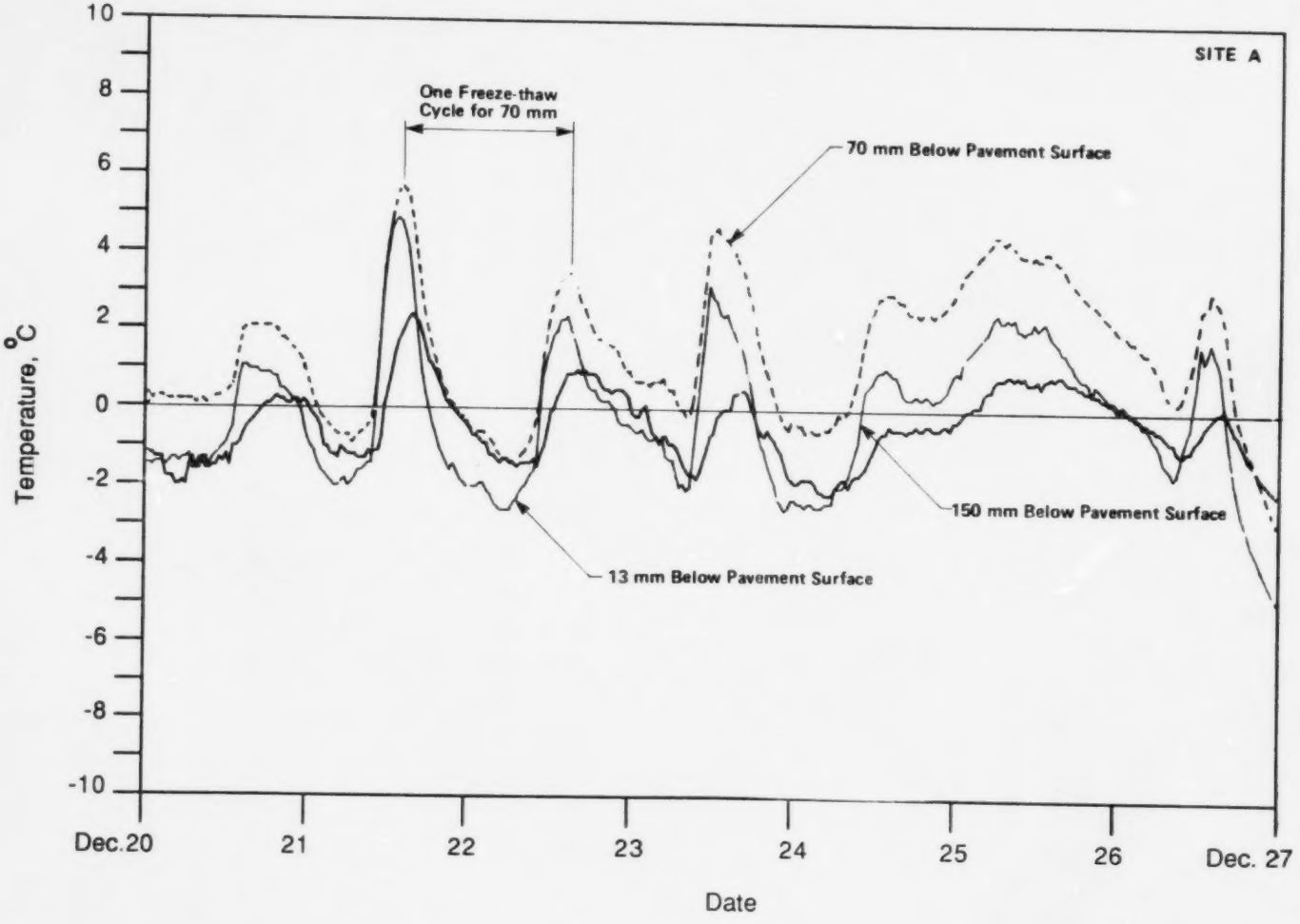


Figure 22/ Temperature Records for Site A for the Week Starting on Dec. 20, 1987

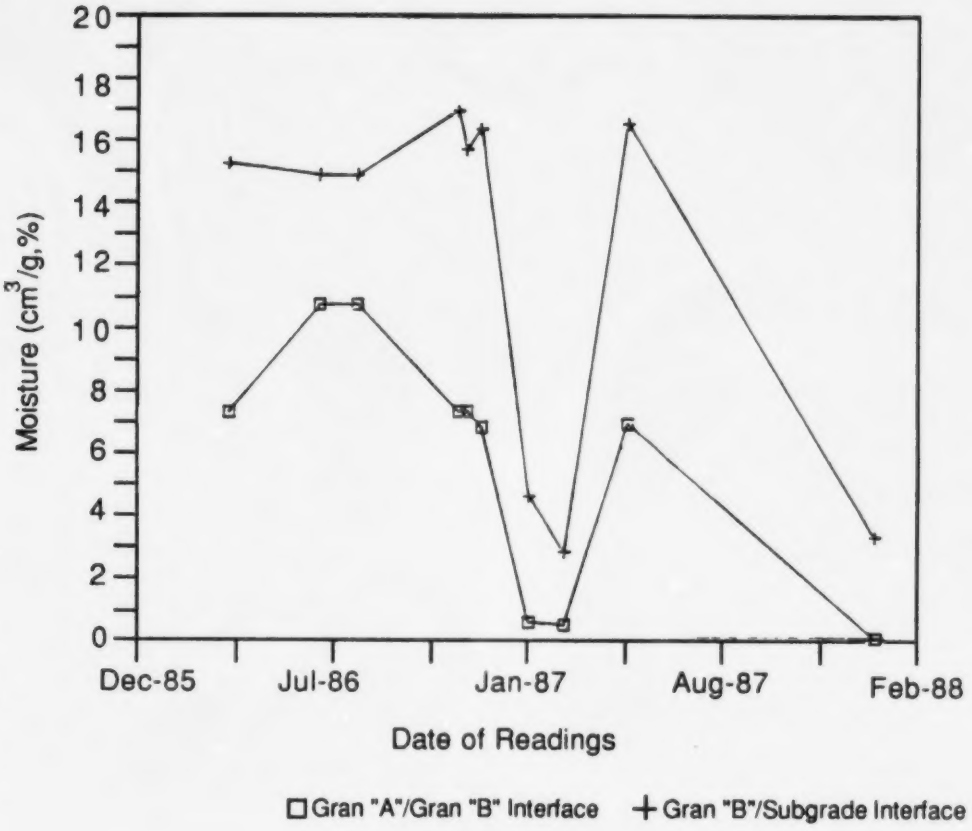


Figure 23/ Variation in Moisture on Site A

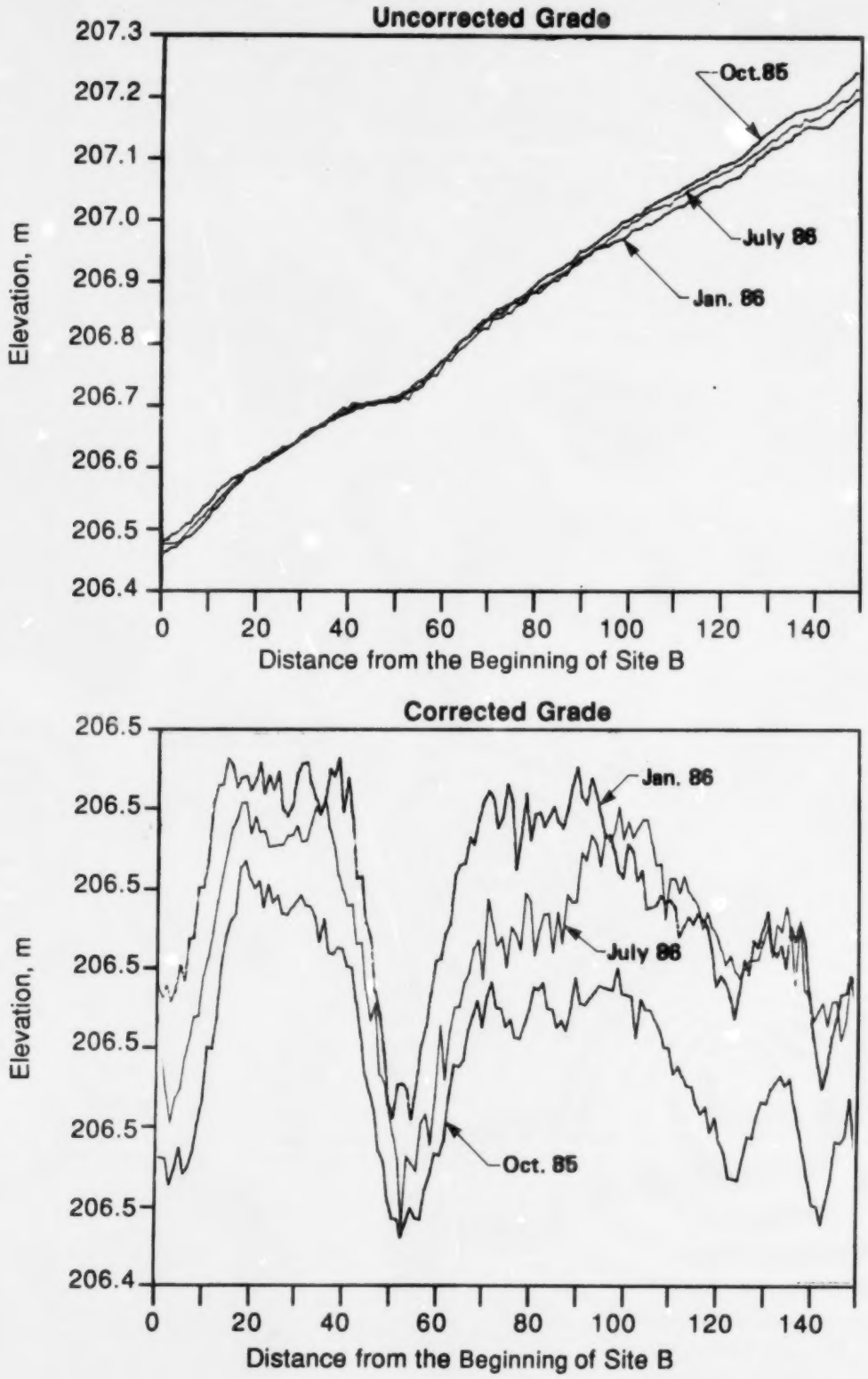


Figure 24/ The Results of Pavement Profile Monitoring, Site B, Lane 3, Right Wheel Path